OPEN ENDED COAXIAL LINE FOR ELECTRICAL CARACTERIZATION OF HUMAN BLOOD

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Abstract- **An open-ended coaxial line was used for measurement of the complex permittivity of human blood. In dielectric characterization, modelization of the probe is a fundamental step, who permit to obtain the relationship between the complex electric admittance and the complex permittivity. The electrical equivalent circuit model was investigated and these performances for blood measurement were estimated. In this paper we present the evaluation of a probe configuration as regard to the frequency and the permittivity range measurement. The proposed model permits us to obtained result on fresh heparined human blood close to the literature value.**

Keywords **- Dielectric parameters, bio-impedance, open-ended probe, blood**

I. INTRODUCTION

Interaction between biological tissue and electromagnetic wave can be approached by two different ways. One may take an interest to the eventual biological effects or use this interaction for the purpose of diagnostic. In these two cases, the quantification of the phenomena is subject to the determination of the electrical behaviour of the biological tissue (electrical permittivity and conductivity). Determining these electrical characteristic requires a specific instrumentation such as a material analyser HP 4291A used in this work to measure electrical impedances in the frequency range 1Mhz–1.8Ghz. This instrumentation is associated to an open-ended coaxial line. This type of sensor, frequently used in the range of microwaves for measures on solid biological tissue and liquid, constitutes a perfectly suitable solution for measure on blood.

The fundamental step in the dielectric measure is the modelization of the sensor, which relates the complex permittivity of the biological tissue to the measured electrical impedance. There are two principal approaches to determine dielectric behaviours with an open coaxial line. The more frequently used consists in modellizing the end of the coaxial probe as an equivalent electrical circuit with lumped element [1]. The other way is based on a more or less rigorous analysis of the electromagnetic field in the probe and in the tissue [2, 3, 4]. The choice between one or the other is dictated, among others, by the permittivity range to measure, the probe dimension, the frequency of the measure and also by the power and the computing time available.

II. MODEL FOR DETERMINING THE PERMITTIVITY

A. Equivalent electrical method

The termination of our probe is modellized by an equivalent electrical circuit (Fig. 1). This circuit is constituted of two capacitances C_t and C_m representing respectively the fringing field effects in the material filling the line and in the biological tissue. At low frequency, the two capacitances are constant and depend only on the probe dimensions. When the frequency increases, the value of C_m increases due to the TH evanescent mode excited at the discontinuity of the coaxial line. At low frequency, the two capacitances are sufficient to modellized the electrical behaviour. At higher frequency, the probe is radiating and a conductance G_R must be included in the equivalent electrical circuit.

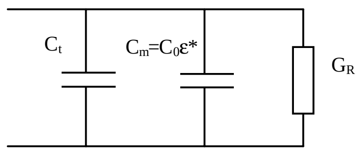

Fig.1. Electrical equivalent circuit

B. Full wave analyze method

The most complete analyse was given by Mosig [2]. In this approach, the reflection coefficient of the TEM mode in the coaxial line is obtained numerically by matching the electromagnetic field at the interface between the coaxial line and the biological tissue. This method takes into account all the phenomena (TH modes, radiating effect) and is then very accurate. We can use it to solve a direct problem ($\varepsilon^* \rightarrow$ Z, Y, Γ), but for an inverse problem (Z , Y, $\Gamma \rightarrow \varepsilon^*$) this technique needs a lot of computing time not adapted for a dielectric caracterization in a wide frequency range.
Dielectric caracterization is possible, with this approach, by making hypothesis like those proposed by Misra [3] and Markuvitz [4]. They express the electric admittance measure by considering the radiating effect at the end of the probe but by neglecting TH modes.

The Markovitz expression with $Y(\omega)=G(\omega)+iB(\omega)$ is :

$$G(\omega)=\frac{Y_0\sqrt{\varepsilon_{test}}}{\pi\ln\frac{b}{a}\sqrt{\varepsilon_{line}}}\int_0^{\pi/2}\frac{1}{\sin\phi}\left[J_0(k_0\sqrt{\varepsilon_{test}}\,b\sin\phi)-J_0(k_0\sqrt{\varepsilon_{test}}\,a\sin\phi)\right]^2 d\phi \qquad (1)$$

$$B(\omega)=\frac{Y_0\sqrt{\varepsilon_{Test}}}{\pi\ln\frac{b}{a}\sqrt{\varepsilon_{tline}}}\int_0^{\pi}2Si(k_0\sqrt{\varepsilon_{test}(a^2+b^2-2ab\cos\phi)})$$

$$-2Si(2k_0\sqrt{\varepsilon_{test}}\,a\sin\frac{\phi}{2})-2Si(2k_0\sqrt{\varepsilon_{test}}\,b\sin\frac{\phi}{2})d\phi \qquad (2)$$

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Abstract

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and the Misra formula is :

$$Y(\omega)=j\frac{Y_0 k_0\sqrt{\varepsilon_{test}}}{k_0\sqrt{\varepsilon_{line}}\,\pi\ln\frac{b}{a}}\int_a^b\int_a^b\int_0^\pi \cos\phi'\frac{\exp(-jk_0\sqrt{\varepsilon_{test}}\,r)}{r}d\rho d\rho' d\phi' \qquad (3)$$

where, $r=\sqrt{\rho^2-\rho'^2-2\rho\rho'\cos(\psi)+z}$, k_0 the propagation constant in free space, a and b the inner and the outer radii respectively, Y_0 the electrical characteristic admittance, ε_{test} et ε_{line} the relative permittivity of the material under test and of the material filling the line respectively, J_0 is the Bessel function of order 0 and Si the sine integral function.
For dielectric caracterization these two expressions must be expanded on a serie form which is more convenient for numerical solution. An iterative technique (Newton-Raphson method) must also be used to solved the inverse problem.

III. Evaluation of the lumped circuit model

A. Method

The modelization of the open-ended coaxial line used for dielectric caracterization of human blood was made with an electrical equivalent circuit [5]. Frequently used and easy to implement, this model permits to obtain simple expression of the complex permittivity.
This method has been established with some hypothesis (C_t constant, no radiating effect...) that will be valid for given frequency and permittivity range. Validation of the model was made with products of known permittivity like water, ethanol, methanol...[5] However, the dielectrics characteristic of blood are very different from those products. Thus, this procedure does not certify that the modelization will be efficient for measure on blood. To estimate the performance of these models we propose to compare it with the point matching theory of Mosig. This technique takes into account all the physical effects appearing at the interface probe-blood and so it constitutes a very precise model, which can be used as a reference.
The permittivity values brought together by Gabriel [6] and modelized by a Cole-Cole answer with two relaxation times (4) allow us to determine, using the point matching theory, the electrical admittance of blood.

$$\varepsilon(\omega)=\varepsilon_\infty+\sum_{m=1}^{2}\frac{\Delta\varepsilon_m}{1+(j\omega\tau_m)^{(1-\alpha_m)}}-j\frac{\sigma_s}{\omega\varepsilon_0} \qquad (4)$$

Where $\varepsilon_\infty=4$, $\Delta\varepsilon_1=56$, $\Delta\varepsilon_2=5200$, $\tau_1=8.377$(ps), $\tau_2=132$(ms), $\alpha_1=0.1$, $\alpha_2=0.1$, $\sigma_s=0.7$ (S/m).

These admittances constitute our references and are assimilated to the value measured at the end of the coaxial probe in contact with blood. With these values we determine the permittivity and the conductivity using the electrical equivalent circuit modelization. The performances of this model are estimated by comparing the results obtained with the dielectric profile given by (4).

B. Results and discussion

Results below (fig. 2 and 3) represent the error in percent on the permittivity and conductivity values induced by the electrical equivalent circuit compared to the point matching theory with 5 higher TH modes. Values were found using an open ended coaxial probe of inner and outer radii 1.5mm and 5mm respectively, filling with Teflon (ε_{line}=2 .1) and with characteristic admittance of 0.02S.
The elements of the electrical equivalent circuit were determined using reference liquid (water, methanol, ethanol and glycerol) by supposing the radiating losses negligible (G_R=0) [5].

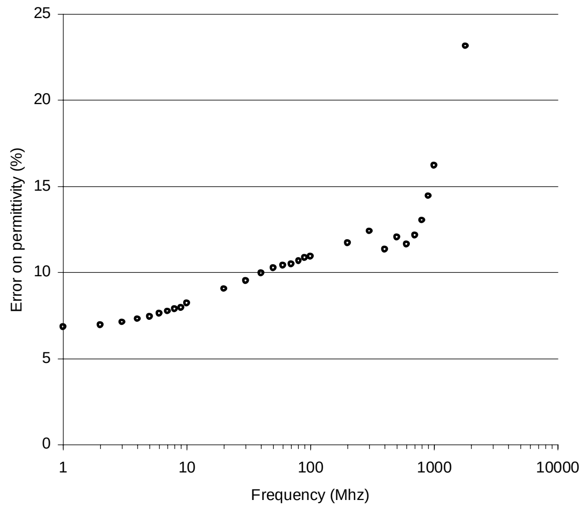

Fig.2. Percentage of error on the permittivity

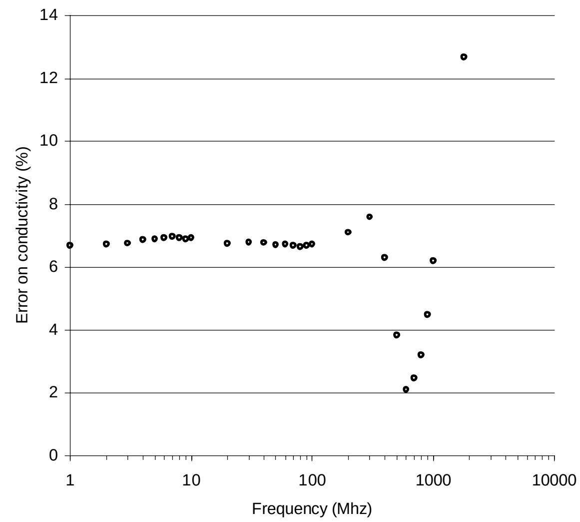

Fig.3. Percentage of error on the conductivity

The equivalent electrical circuit permits a measure on the 1Mhz-1Ghz frequency range with a 16% and 8% of precision respectively for the permittivity and the conductivity. After 1Ghz the error increased due to the apparition of radiating effects, which are not taken into account in the model. To increase the precision, the ideal would be to dispose of standard loads close to the dielectric properties of blood, which can be used for calibration of the instrumentation and determination of the lumped electric parameters. But this represents the main difficulties of the measure on biological tissue. Taking into account all these problems and the fact that measures on biological organs are different for and proper to each individual, the electrical equivalent circuit constitutes a simple solution, which will be used for measure on blood in the 1Mhz-1Ghz frequency range.

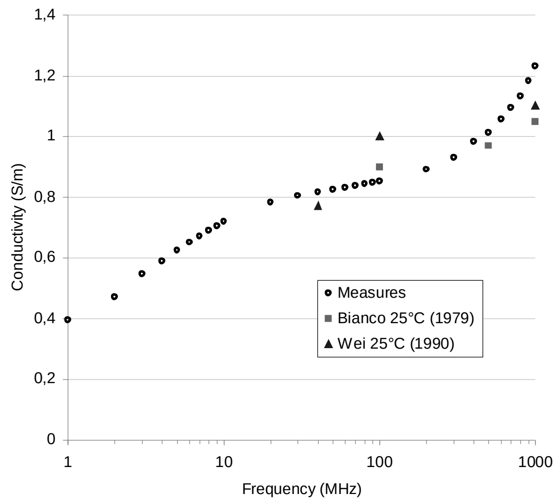

Fig. 4. Conductivity of human blood at 21°C

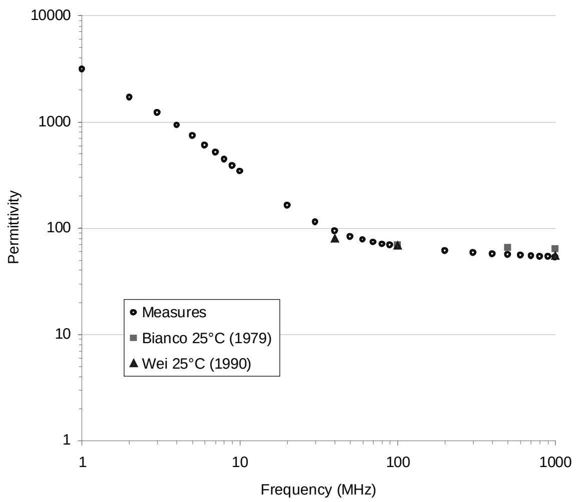

Fig. 5. Permittivity of human blood at 21°C

IV. Measure on human blood

The following measurements (Fig 4 and 5) were made on fresh heparined human blood (8000 units per 20ml) at 21°C. These values were obtained using the open-ended coaxial line described in the last section and modelized by an equivalent electrical circuit. The results are compared to few values of human blood given in the literature

V. Conclusion

Precise measure of dielectric parameters with an open-ended coaxial line is only possible with an adapted modelization of the sensor. For each model, the hypothesis expressed will be valid only for one frequency range and one permittivity special range. The validation method used brings out the performances of the electrical equivalent lumped circuit. This modelization permits us to obtain simple expression of the complex permittivity adapted for measure on blood in the frequency range 1Mhz-1Ghz.

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